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# A BURST FIRE ALGORITHM



TRADOC ANALYSIS COMMAND

OPERATIONS ANALYSIS CENTER

MODEL DEVELOPMENT & MAINTENANCE DIRECTORATE

FORT LEAVENWORTH, KS 66027-5200

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January 1990

TRADOC Analysis Command-Fort Leavenworth (TRAC-FLVN)
Model Support Directorate
Fort Leavenworth, Kansas 66027-5200

# A BURST FIRE ALGORITHM

by

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This report describes a methodology put into a preprocessor for computer wargame models. The preprocessor computes kill rates or probability of kills (Pk) for selected direct fire waepons against selected targets. These are input data used by the wargame models.

The methodology replaced a methodology already in the preprocessor. This methodology computes probability of his (Ph) and probability of kill given a hit (Pk/h) for a particular type of weapon fired against the target. The weapon type fires a designated number of rounds in bursts and is called a burst fire weapon. Ph and Pk/h are intermediate values used in computing the kill rate of Pk.

The new methodology was needed to reduce computer time when processing the burst fire type weapons. The old methodllogy was a Monte Carlo process which takes more time than other methods.


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## ABSTRACT

This report describes a methodology put into a preprocessor for computer wargame models. The preprocessor computes kill rates or probability of kills (Pk) for selected direct fire weapons against selected targets. These are input data used by the wargame models.

The methodology replaced a methodology already in the preprocessor. This methodology computes probability of hit (Ph) and probability of kill given a hit (Pk/h) for a particular type of weapon fired against the target. The weapon type fires a designated number of rounds in bursts and is called a burst fire weapon. Ph and Pk/h are intermediate values used in computing the kill rate or Pk.

The new methodology was needed to reduce computer time when processing the burst fire type weapons. The old methodology was a Monte Carlo process which takes more time than other methods.

1. Introduction. TRADOC Analysis Command at White Sands Missile Range (TRAC-WSMR) has developed a program called Direct Fire Weapon Preprocessor (DFWP) which computes kill rates for Vector In Commander (VIC) and other computer wargame models. The kill rate data are for selected direct fire weapons against selected targets. TRAC at Fort Leavenworth (TRAC-FLVN) uses DFWP with modifications. F-DFWP shall refer to FLVN's DFWP and W-DFWP shall refer to WSMR's DFWP. Because of long computer time used for burst fire type weapons, a methodology for these weapons in W-DFWP was not adequate for F-DFWP. This report discusses the problem and defines the solution.

2. Problem. The methodologies for probability of hit (Ph) and probability of kill given a hit (Pk/h) needed to be changed.

a. Overview of Ph computation.

(1) DFWP uses two kinds of data.

(a) One is the target dimensions. This is available from the Ballistic Research Laboratory (BRL).

(b) The other is the probability data for round impacts of the weapon. This is available from the Army Materiel Systems Analysis Activity (AMSAA).

(2) DFWP computes the Ph from the target dimensions and weapon probability data.

b. Overview of Pk/h computation.

(1) BRL provides the Pk/h data for a round.

(2) DFWP uses the Pk/h data "as is" for non burst fire weapons. DFWP recomputes the Pk/h data for burst fire weapons.

c. Ph computation for burst fire weapons.

(1) Probability data. Burst fire weapons have a probability density function (pdf) p$\underline{b}$(X,Y) for bursts centered at (X,Y) in addition to a pdf p$\underline{r}$(x,y) for the round impacts. Pdf p$\underline{r}$(x,y) is actually a conditional pdf for round impact at (x,y) given that the burst is centered at (X,Y). Pdf p$\underline{r}$(x,y) may be written p$\underline{r}$(x,y | X,Y).

(2) Description. Ph for burst fire weapons is the probability that a burst will have at least one round hitting the target.

(3) Formulas.

$$Ph = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p\underline{b}(X,Y) * Ph\underline{b}(X,Y)\, dY\, dX$$

Ph$\underline{b}$(X,Y) is the Ph for a burst centered at (X,Y). Ph$\underline{b}$(X,Y) may be found by the power-up formula:

$$Ph\underline{b}(X,Y) = 1 - (1 - Ph\underline{r}(X,Y)) ** Rnds$$

Rnds is the number of rounds in a burst. Ph$\underline{r}$(X,Y) is the Ph for a round in a burst centered at (X,Y). Ph$\underline{r}$(X,Y) is found by integrating p$\underline{r}$(x,y) over the target area.

$$Ph\underline{r}(X,Y) = \iint_{\text{Target area}} p\underline{r}(x,y \mid X,Y)\, dy\, dx$$

d. Pk/h computation for burst fire weapons.

(1) Description. Pk/h for burst fire weapons is the probability of kill (Pk) if there is at least one hit in a burst.

(2) Formulas.

$$Pk/h = Pk / Ph$$

$$Pk = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p\underline{b}(X,Y) * Pk\underline{b}(X,Y)\, dY\, dX$$

Pk$\underline{b}$(X,Y) is the Pk for a burst centered at (X,Y). Pk$\underline{b}$(X,Y) may be found by the power-up formula.

$$Pk\underline{b}(X,Y) = 1 - (1 - Pkh\underline{r} * Ph\underline{r}(X,Y)) ** Rnds$$

Pkh$\underline{r}$ is the Pk/h data supplied by BRL.

e. Problem. DFWP computes Ph and Pk/h for about 1,000 combinations of range, aspect angle, posture, and movement condition. W-DFWP used a Monte Carlo process to compute Ph and Pk/h. It uses a significant amount of computer time. F-DFWP needed a more efficient methodology to compute Ph and Pk/h.

3. <u>Assumptions</u>.

a. The DFWP assumes the targets to be a box or two boxes, one on top of the other. If two boxes are assumed, then the bottom box is called the hull, and the top box is called the turret. The turret is assumed to be exactly on the center of the hull. (See figure 1.) (This might change in the future.)

b. The DFWP assumes $p_b(X,Y)$ to be normal and independent in the horizontal and vertical directions. Therefore, $p_b(X,Y)$ is an uncorrelated binormal pdf. The DFWP also assumes $p_r(x,y)$ to be normal and independent in the horizontal and vertical with mean given by the burst center (X,Y).

c. The DFWP assumes the flight path to be parallel to the ground.

d. The DFWP assumes the aimpoint to be the center of target.

4. <u>The old methodology</u>. The W-DFWP methodology computes Ph and Pk (the integrals in paragraphs 2c(3) and 2d(2)) by a two stage simulation.

a. First stage. 2,000 bursts are simulated. A table of normal random numbers supplies an X and a Y value for each burst center.

b. $Ph_r(X,Y)$ computation. A burst center, (X,Y), is the mean of $p_r(x,y)$. This mean and the round standard deviation data determine $p_r(x,y)$. W-DFWP computes $Ph_r$ by integrating $p_r(x,y)$ over the hull and turret areas. (See figure 1.)

$$Ph_r \quad = \quad \text{Ph on hull} \quad + \quad \text{Ph on turret}$$

$$Ph_r = \int_{X1}^{X4} \int_{Y1}^{Y2} p_r(x,y)\, dy\, dx + \int_{X2}^{X3} \int_{Y2}^{Y3} p_r(x,y)\, dy\, dx$$

Pdf $p_r(x,y)$ equals the product of normal pdfs in X and Y directions.

$$p_r(x,y) = f(x) * f(y)$$

(The X measurements are in units of round X standard deviation, and the Y measurements are in units of round Y standard deviation.) Each double integral can be changed into a product of two single integrals, thus:

$$Ph_r = \int_{X1}^{X4} f(x)\,dx * \int_{Y1}^{Y2} f(y)\,dy + \int_{X2}^{X3} f(x)\,dx * \int_{Y2}^{Y3} f(y)\,dy$$

Each integral can be evaluated from two lookups in the normal distribution table.

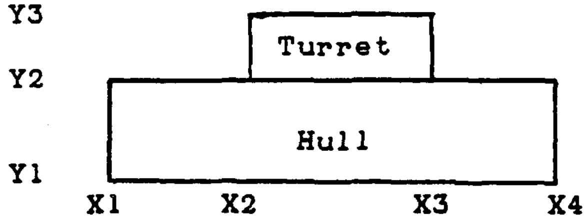


Figure 1. Target area

c. Second stage. $Ph_b(X,Y)$ and $Pk_b(X,Y)$ are not computed by the power-up formulas (paragraphs 2c(3) and 2d(2)). Instead, a simulation is done which returns a value of one or zero, indicating whether a hit is made in the burst, and a value of one or zero, indicating whether a kill is made. The simulation is such that the probability of returning a one for a hit is $Ph_b(X,Y)$ and the probability of returning a one for a kill is $Pk_b(X,Y)$. The generator generates two random numbers in [0,1] for each round in the burst. It compares the first number to $Ph_r$ to determine if a hit is made. If a hit is made, it compares the second number to $Pkh_r$ to determine if a kill is made.

d. Ph and Pk computation. W-DFWP computes Ph as the number of burst hits divided by 2,000 and Pk as the number of burst kills divided by 2,000.

e. Mathematical description. Pdf $p_b(X,Y)$ equals the product of normal pdfs in X and Y directions.

$$p_b(X,Y) = f(X) * f(Y)$$

(The X measurements are in units of burst X standard deviation, and the Y measurements are in units of burst Y standard deviation.) The formulas in paragraphs 2c(3) and 2d(2) may be written:

$$Ph = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(X) * f(Y) * Ph_b(X,Y)\,dY\,dX$$

$$Pk = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(X) * f(Y) * Pk\underline{b}(X,Y)\, dY\, dX$$

Make the following substitutions:

$$U = F(X) = \int_{-\infty}^{X} f(T)\, dT, \quad V = F(Y) = \int_{-\infty}^{Y} f(T)\, dT$$

$$dU = f(X)\, dX, \quad dV = f(Y)\, dY.$$

This changes the formulas to:

$$Ph = \int_{0}^{1}\int_{0}^{1} Ph\underline{b}(X,Y)\, dV\, dU, \qquad Pk = \int_{0}^{1}\int_{0}^{1} Pk\underline{b}(X,Y)\, dV\, dU$$

The inverse normal table must compute X and Y from U and V.

$$X = F^{-1}(U), \quad Y = F^{-1}(V)$$

The Monte Carlo process would use random numbers in [0,1] for U and V. Then the inverse normal table would compute X and Y from U and V. X and Y would be normal random numbers.

5. <u>The new methodology</u>. The F-DFWP methodology replaces the two stage simulation in the W-DFWP methodology by direct methods.

a. First stage. Two direct methods were tried to replace the first stage simulation in the W-DFWP methodology. The methods use deterministic Us and Vs, instead of random Us and Vs. The inverse normal table then computes the Xs and Ys (as in paragraph 4e).

$$X = F^{-1}(U), \quad Y = F^{-1}(V)$$

(1) Equally spaced method. The first direct method tried divides [0,1] into equal intervals. The Us and Vs are the midpoints of these intervals. Combinations of the Us and Vs are the midpoints of square intervals. These square intervals divide up the area of integration which is the unit square. If [0,1] is divided into 10 intervals, then values of U and V would be .05, .15, ..., .95, and there would be 100 combinations of Us and Vs or burst simulations.

(2) Gauss method. The second direct method tried divides [0,1] into unequal intervals. A Gauss algorithm determines beforehand the Us and Vs. F-DFWP implements this method. (Numerical analysis books describe the Gauss method for numerical integration. See for example Schaum's Outline of Numerical Analysis.)

b. Ph_r_(X,Y) computation. The F-DFWP methodology computes Ph_r_ the same way as the W-DFWP methodology (paragraph 4b).

c. Second stage. The F-DFWP methodology replaces the second stage simulation in W-DFWP by using the power-up formulas in paragraphs 2c(3) and 2d(2) to compute Ph_b_ and Pk_b_. The integrals for Ph and Pk in paragraph 4e may, therefore, be written as:

$$Ph = \int_0^1 \int_0^1 (1 - (1 - Ph\underline{r}(X,Y))^{Rnds})\, dV\, dU$$

$$Pk = \int_0^1 \int_0^1 (1 - (1 - Pkh\underline{r} * Ph\underline{r}(X,Y))^{Rnds})\, dV\, dU$$

d. Ph and Pk computation. Ph_b_ and Pk_b_ (integrands of the integrals in paragraph 5c) are computed for all combinations of X and Y (paragraph 5a).

(1) Equally spaced method. Ph is computed as the average of the Ph_b_s and Pk is computed as the average of the Pk_b_s.

(2) Gauss method. The Ph_b_s and Pk_b_s are not averaged as in the equally spaced method but are weighted and summed. The weights are determined beforehand at the same time as the Us and Vs by the Gauss algorithm.

6. Computer program Burst_Ph.

a. Description. Program Burst_Ph compares the methodologies. Inputs to the program are the target dimensions. The program sets the X & Y burst dispersions to two. It computes for combinations of different burst bias, round dispersion, range, number of rounds in burst, and Pkh_r_. Output is labeled Monte Carlo, Summate, and Gauss. Monte Carlo is the old methodology, Summate is the equally spaced methodology, and Gauss is the Gauss methodology.

Appendix A contains output from the program. Hull length and height inputs are five and two and turret length and height inputs are two and one.

b. Conclusions. The difference between the Gauss values for the different number of iterations in the program outputs is usually much less than the difference between the Summate values for the different iterations. Also, as the iterations increase, in which case the accuracy increases, the Summate values appear to converge to the Gauss values. These observations indicate that the Gauss method is much more accurate than the Summate method.

The accuracy of the Monte_Carlo method varies. Usually it looks less accurate than the Summate method for 400 and 1,600 repetitions. It appears less accurate for PROB. of KILL/HIT than for PROB. of HIT.

It appears that the Gauss method using 400 or fewer iterations will give greater accuracy than the 2,000 repetition Monte Carlo method (the old methodology).

## APPENDIX A

## BURST_PH OUTPUT

```
HULL LENGTH AND HEIGHT?
 5.000   2.000
TURRET LENGTH AND HEIGHT?
 2.000   1.000


                          X      Y
ROUND DISPERSION   =    1.00   1.00
BURST BIAS         =    0.00   0.00

ROUNDS   =     5
RANGE    =   200.
```

PROB. of HIT

| | Iterations 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 0.99999 | |
| GAUSS | 0.99999 | 0.99991 | 0.99986 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.40000 |
| SUMMATE | 0.40912 | 0.40879 | 0.40854 | |
| GAUSS | 0.40846 | 0.40829 | 0.40820 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.97100 |
| SUMMATE | 0.96856 | 0.96836 | 0.96816 | |
| GAUSS | 0.96810 | 0.96790 | 0.96785 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.99950 |
| SUMMATE | 0.99999 | 0.99999 | 0.99998 | |
| GAUSS | 0.99997 | 0.99994 | 0.99994 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 0.00 | 0.00 |

ROUNDS = 5
RANGE = 800.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.73800 |
| SUMMATE | 0.75644 | 0.74284 | 0.73937 | |
| GAUSS | 0.73802 | 0.73876 | 0.73877 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.23645 |
| SUMMATE | 0.24965 | 0.25194 | 0.25269 | |
| GAUSS | 0.25301 | 0.25283 | 0.25282 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.80623 |
| SUMMATE | 0.78946 | 0.79330 | 0.79475 | |
| GAUSS | 0.79539 | 0.79502 | 0.79502 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.97764 |
| SUMMATE | 0.97482 | 0.97562 | 0.97599 | |
| GAUSS | 0.97616 | 0.97606 | 0.97606 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 0.00 | 0.00 |

ROUNDS = 5
RANGE = 3000.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.17300 |
| SUMMATE | 0.16825 | 0.16835 | 0.16836 | |
| GAUSS | 0.16835 | 0.16836 | 0.16835 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.14162 |
| SUMMATE | 0.12014 | 0.12013 | 0.12013 | |
| GAUSS | 0.12013 | 0.12013 | 0.12013 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.53468 |
| SUMMATE | 0.55297 | 0.55293 | 0.55293 | |
| GAUSS | 0.55293 | 0.55293 | 0.55293 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.91329 |
| SUMMATE | 0.91806 | 0.91805 | 0.91805 | |
| GAUSS | 0.91805 | 0.91805 | 0.91805 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 0.00 | 0.00 |

ROUNDS = 20
RANGE = 200.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 1.00000 | |
| GAUSS | 1.00000 | 1.00000 | 0.99999 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.87000 |
| SUMMATE | 0.87809 | 0.87780 | 0.87752 | |
| GAUSS | 0.87743 | 0.87714 | 0.87703 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 1.00000 | |
| GAUSS | 1.00000 | 0.99999 | 0.99996 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 1.00000 | |
| GAUSS | 1.00000 | 1.00000 | 1.00000 | |

|  | X | Y |
|---|---|---|
| ROUND DISPERSION = | 1.00 | 1.00 |
| BURST BIAS = | 0.00 | 0.00 |

ROUNDS = 20
RANGE = 800.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.87250 |
| SUMMATE | 0.90618 | 0.88024 | 0.87243 | |
| GAUSS | 0.87083 | 0.86932 | 0.86939 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.55989 |
| SUMMATE | 0.56163 | 0.57100 | 0.57458 | |
| GAUSS | 0.57509 | 0.57637 | 0.57633 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.93238 |
| SUMMATE | 0.92508 | 0.93135 | 0.93272 | |
| GAUSS | 0.93210 | 0.93443 | 0.93438 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.99198 |
| SUMMATE | 0.99014 | 0.99147 | 0.99147 | |
| GAUSS | 0.99139 | 0.99183 | 0.99181 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 0.00 | 0.00 |

ROUNDS = 20
RANGE = 3000.

PROB. of HIT

| | Iterations 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.38100 |
| SUMMATE | 0.38640 | 0.38683 | 0.38686 | |
| GAUSS | 0.38685 | 0.38686 | 0.38686 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.19948 |
| SUMMATE | 0.19390 | 0.19379 | 0.19379 | |
| GAUSS | 0.19379 | 0.19379 | 0.19378 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.68635 |
| SUMMATE | 0.69213 | 0.69190 | 0.69189 | |
| GAUSS | 0.69189 | 0.69189 | 0.69188 | |

PROB. of KILL/HIT
ROUND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.95538 |
| SUMMATE | 0.95372 | 0.95365 | 0.95365 | |
| GAUSS | 0.95365 | 0.95365 | 0.95364 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 5
RANGE = 200.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.99750 |
| SUMMATE | 0.99996 | 0.99961 | 0.99901 | |
| GAUSS | 0.99882 | 0.99853 | 0.99835 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.39599 |
| SUMMATE | 0.40541 | 0.40448 | 0.40409 | |
| GAUSS | 0.40396 | 0.40354 | 0.40345 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.96742 |
| SUMMATE | 0.96601 | 0.96488 | 0.96450 | |
| GAUSS | 0.96434 | 0.96405 | 0.96384 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.99950 |
| SUMMATE | 0.99989 | 0.99973 | 0.99967 | |
| GAUSS | 0.99963 | 0.99964 | 0.99959 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 5
RANGE = 800.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.58200 |
| SUMMATE | 0.58851 | 0.57904 | 0.57348 | |
| GAUSS | 0.57139 | 0.57099 | 0.57102 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.22079 |
| SUMMATE | 0.23464 | 0.23366 | 0.23444 | |
| GAUSS | 0.23476 | 0.23496 | 0.23495 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.77406 |
| SUMMATE | 0.76656 | 0.76336 | 0.76449 | |
| GAUSS | 0.76494 | 0.76546 | 0.76545 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.97509 |
| SUMMATE | 0.97040 | 0.96932 | 0.96949 | |
| GAUSS | 0.96954 | 0.96973 | 0.96973 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 5
RANGE = 3000.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.11250 |
| SUMMATE | 0.11640 | 0.11570 | 0.11569 | |
| GAUSS | 0.11570 | 0.11569 | 0.11569 | |

PROB. of KILL/HIT
ROUND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.13778 |
| SUMMATE | 0.11884 | 0.11907 | 0.11908 | |
| GAUSS | 0.11907 | 0.11908 | 0.11908 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.57333 |
| SUMMATE | 0.54958 | 0.55021 | 0.55023 | |
| GAUSS | 0.55021 | 0.55022 | 0.55023 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.93778 |
| SUMMATE | 0.91691 | 0.91714 | 0.91714 | |
| GAUSS | 0.91714 | 0.91714 | 0.91714 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 20

RANGE = 200.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.99900 |
| SUMMATE | 1.00000 | 1.00000 | 0.99999 | |
| GAUSS | 0.99999 | 0.99975 | 0.99974 | |

PROB. of KILL/HIT

RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.86737 |
| SUMMATE | 0.87441 | 0.87285 | 0.87187 | |
| GAUSS | 0.87154 | 0.87107 | 0.87074 | |

PROB. of KILL/HIT

RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 0.99996 | 0.99978 | |
| GAUSS | 0.99973 | 0.99958 | 0.99958 | |

PROB. of KILL/HIT

RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 0.99999 | |
| GAUSS | 0.99999 | 0.99996 | 0.99996 | |

|  | X | Y |
|---|---|---|
| ROUND DISPERSION = | 1.00 | 1.00 |
| BURST BIAS = | 1.20 | 1.50 |

ROUNDS = 20
RANGE = 800.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.72800 |
| SUMMATE | 0.73875 | 0.73209 | 0.72901 | |
| GAUSS | 0.72843 | 0.72392 | 0.72401 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.49657 |
| SUMMATE | 0.51729 | 0.51151 | 0.50967 | |
| GAUSS | 0.50860 | 0.51175 | 0.51172 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.90934 |
| SUMMATE | 0.90412 | 0.90357 | 0.90007 | |
| GAUSS | 0.89859 | 0.90100 | 0.90096 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.98970 |
| SUMMATE | 0.98686 | 0.98724 | 0.98666 | |
| GAUSS | 0.98649 | 0.98671 | 0.98670 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 1.00 | 1.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 20
RANGE = 3000.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.27800 |
| SUMMATE | 0.27822 | 0.27363 | 0.27351 | |
| GAUSS | 0.27366 | 0.27353 | 0.27353 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.18345 |
| SUMMATE | 0.18509 | 0.18729 | 0.18736 | |
| GAUSS | 0.18727 | 0.18735 | 0.18736 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.68885 |
| SUMMATE | 0.67520 | 0.67997 | 0.68016 | |
| GAUSS | 0.67998 | 0.68014 | 0.68015 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.95683 |
| SUMMATE | 0.94929 | 0.95064 | 0.95070 | |
| GAUSS | 0.95067 | 0.95070 | 0.95070 | |

| | X | Y |
|---|---|---|
| ROUND DISPERSION = | 4.00 | 5.00 |
| BURST BIAS = | 0.00 | 0.00 |

ROUNDS = 5
RANGE = 200.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.99850 |
| SUMMATE | 0.99921 | 0.99910 | 0.99901 | |
| GAUSS | 0.99899 | 0.99891 | 0.99888 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.32098 |
| SUMMATE | 0.33202 | 0.33116 | 0.33073 | |
| GAUSS | 0.33058 | 0.33038 | 0.33034 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.91838 |
| SUMMATE | 0.91362 | 0.91263 | 0.91211 | |
| GAUSS | 0.91193 | 0.91166 | 0.91159 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.99700 |
| SUMMATE | 0.99787 | 0.99776 | 0.99770 | |
| GAUSS | 0.99768 | 0.99764 | 0.99762 | |

| | X | Y |
|---|---|---|
| ROUND DISPERSION = | 4.00 | 5.00 |
| BURST BIAS = | 0.00 | 0.00 |

ROUNDS = 5
RANGE = 800.

PROB. of HIT

| | Iterations 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.45350 |
| SUMMATE | 0.45708 | 0.45387 | 0.45234 | |
| GAUSS | 0.45182 | 0.45118 | 0.45103 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.11466 |
| SUMMATE | 0.12337 | 0.12326 | 0.12323 | |
| GAUSS | 0.12322 | 0.12322 | 0.12322 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.57552 |
| SUMMATE | 0.56173 | 0.56145 | 0.56136 | |
| GAUSS | 0.56133 | 0.56133 | 0.56133 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.93826 |
| SUMMATE | 0.92113 | 0.92104 | 0.92101 | |
| GAUSS | 0.92100 | 0.92100 | 0.92100 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 4.00 | 5.00 |
| BURST BIAS | = | 0.00 | 0.00 |

ROUNDS = 5
RANGE = 3000.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.04300 |
| SUMMATE | 0.04367 | 0.04330 | 0.04314 | |
| GAUSS | 0.04308 | 0.04302 | 0.04300 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.10465 |
| SUMMATE | 0.10164 | 0.10164 | 0.10164 | |
| GAUSS | 0.10164 | 0.10164 | 0.10164 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.46512 |
| SUMMATE | 0.50455 | 0.50453 | 0.50453 | |
| GAUSS | 0.50453 | 0.50453 | 0.50453 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.91860 |
| SUMMATE | 0.90163 | 0.90163 | 0.90162 | |
| GAUSS | 0.90162 | 0.90162 | 0.90162 | |

| | X | Y |
|---|---|---|
| ROUND DISPERSION = | 4.00 | 5.00 |
| BURST BIAS = | 0.00 | 0.00 |

ROUNDS = 20
RANGE = 200.

PROB. of HIT

| | Iterations 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 1.00000 | |
| GAUSS | 1.00000 | 1.00000 | 1.00000 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.79650 |
| SUMMATE | 0.80008 | 0.79885 | 0.79820 | |
| GAUSS | 0.79798 | 0.79763 | 0.79753 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.99950 |
| SUMMATE | 0.99993 | 0.99992 | 0.99992 | |
| GAUSS | 0.99991 | 0.99991 | 0.99990 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 1.00000 | |
| GAUSS | 1.00000 | 1.00000 | 1.00000 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 4.00 | 5.00 |
| BURST BIAS | = | 0.00 | 0.00 |

ROUNDS = 20
RANGE = 800.

PROB. of HIT

| | Iterations 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.90200 |
| SUMMATE | 0.90946 | 0.90612 | 0.90427 | |
| GAUSS | 0.90365 | 0.90259 | 0.90230 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.22118 |
| SUMMATE | 0.22754 | 0.22666 | 0.22632 | |
| GAUSS | 0.22620 | 0.22614 | 0.22614 | |

PROB. of KILL/HIT
ROUND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.77661 |
| SUMMATE | 0.76103 | 0.75943 | 0.75877 | |
| GAUSS | 0.75855 | 0.75840 | 0.75839 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.97506 |
| SUMMATE | 0.97194 | 0.97156 | 0.97140 | |
| GAUSS | 0.97134 | 0.97129 | 0.97129 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 4.00 | 5.00 |
| BURST BIAS | = | 0.00 | 0.00 |

ROUNDS = 20
RANGE = 3000.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.15350 |
| SUMMATE | 0.16339 | 0.16204 | 0.16143 | |
| GAUSS | 0.16122 | 0.16099 | 0.16094 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.09121 |
| SUMMATE | 0.10794 | 0.10791 | 0.10790 | |
| GAUSS | 0.10790 | 0.10790 | 0.10790 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.51792 |
| SUMMATE | 0.52157 | 0.52149 | 0.52147 | |
| GAUSS | 0.52146 | 0.52146 | 0.52147 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.91531 |
| SUMMATE | 0.90760 | 0.90757 | 0.90756 | |
| GAUSS | 0.90756 | 0.90756 | 0.90756 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 4.00 | 5.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 5
RANGE = 200.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.99650 |
| SUMMATE | 0.99759 | 0.99728 | 0.99709 | |
| GAUSS | 0.99703 | 0.99688 | 0.99683 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.30858 |
| SUMMATE | 0.31903 | 0.31823 | 0.31785 | |
| GAUSS | 0.31772 | 0.31755 | 0.31751 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.90567 |
| SUMMATE | 0.89923 | 0.89820 | 0.89768 | |
| GAUSS | 0.89750 | 0.89726 | 0.89720 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.99649 |
| SUMMATE | 0.99635 | 0.99620 | 0.99612 | |
| GAUSS | 0.99610 | 0.99605 | 0.99604 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 4.00 | 5.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 5
RANGE = 800.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.42500 |
| SUMMATE | 0.42602 | 0.42319 | 0.42184 | |
| GAUSS | 0.42138 | 0.42081 | 0.42069 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.10941 |
| SUMMATE | 0.12178 | 0.12169 | 0.12166 | |
| GAUSS | 0.12165 | 0.12165 | 0.12165 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.56353 |
| SUMMATE | 0.55766 | 0.55744 | 0.55736 | |
| GAUSS | 0.55733 | 0.55732 | 0.55732 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.93647 |
| SUMMATE | 0.91979 | 0.91971 | 0.91969 | |
| GAUSS | 0.91968 | 0.91967 | 0.91967 | |

| | X | Y |
|---|---|---|
| ROUND DISPERSION = | 4.00 | 5.00 |
| BURST BIAS = | 1.20 | 1.50 |

ROUNDS = 5
RANGE = 3000.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.04000 |
| SUMMATE | 0.04038 | 0.04006 | 0.03991 | |
| GAUSS | 0.03986 | 0.03980 | 0.03979 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.10000 |
| SUMMATE | 0.10155 | 0.10155 | 0.10155 | |
| GAUSS | 0.10155 | 0.10155 | 0.10155 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.46250 |
| SUMMATE | 0.50430 | 0.50428 | 0.50428 | |
| GAUSS | 0.50428 | 0.50428 | 0.50428 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.90000 |
| SUMMATE | 0.90154 | 0.90154 | 0.90154 | |
| GAUSS | 0.90153 | 0.90153 | 0.90153 | |

| | X | Y |
|---|---|---|
| ROUND DISPERSION = | 4.00 | 5.00 |
| BURST BIAS = | 1.20 | 1.50 |

ROUNDS = 20
RANGE = 200.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 1.00000 | |
| GAUSS | 1.00000 | 1.00000 | 1.00000 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.77850 |
| SUMMATE | 0.78209 | 0.78073 | 0.78002 | |
| GAUSS | 0.77978 | 0.77942 | 0.77932 | |

PROB. of KILL/HIT
ROUND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 0.99980 | 0.99977 | 0.99974 | |
| GAUSS | 0.99973 | 0.99971 | 0.99970 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 1.00000 |
| SUMMATE | 1.00000 | 1.00000 | 1.00000 | |
| GAUSS | 1.00000 | 1.00000 | 1.00000 | |

| | | X | Y |
|---|---|---|---|
| ROUND DISPERSION | = | 4.00 | 5.00 |
| BURST BIAS | = | 1.20 | 1.50 |

ROUNDS = 20
RANGE = 800.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.87850 |
| SUMMATE | 0.88154 | 0.87795 | 0.87605 | |
| GAUSS | 0.87540 | 0.87441 | 0.87416 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.20888 |
| SUMMATE | 0.21710 | 0.21644 | 0.21619 | |
| GAUSS | 0.21610 | 0.21605 | 0.21605 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.76039 |
| SUMMATE | 0.74378 | 0.74258 | 0.74209 | |
| GAUSS | 0.74192 | 0.74181 | 0.74180 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.97382 |
| SUMMATE | 0.96815 | 0.96786 | 0.96774 | |
| GAUSS | 0.96770 | 0.96766 | 0.96766 | |

| | X | Y |
|---|---|---|
| ROUND DISPERSION = | 4.00 | 5.00 |
| BURST BIAS = | 1.20 | 1.50 |

ROUNDS = 20
RANGE = 3000.

PROB. of HIT

| | Iterations | | | |
|---|---|---|---|---|
| | 100 | 400 | 1600 | 2000 |
| MONTE_CARLO | | | | 0.14450 |
| SUMMATE | 0.15161 | 0.15044 | 0.14990 | |
| GAUSS | 0.14971 | 0.14950 | 0.14946 | |

PROB. of KILL/HIT
RND PKH = 0.10

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.08304 |
| SUMMATE | 0.10749 | 0.10746 | 0.10746 | |
| GAUSS | 0.10745 | 0.10745 | 0.10745 | |

PROB. of KILL/HIT
RND PKH = 0.50

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.50865 |
| SUMMATE | 0.52037 | 0.52030 | 0.52027 | |
| GAUSS | 0.52026 | 0.52026 | 0.52026 | |

PROB. of KILL/HIT
RND PKH = 0.90

| | 100 | 400 | 1600 | 2000 |
|---|---|---|---|---|
| MONTE_CARLO | | | | 0.92042 |
| SUMMATE | 0.90718 | 0.90715 | 0.90715 | |
| GAUSS | 0.90714 | 0.90714 | 0.90714 | |

## APPENDIX B

## BURST_PH CODE

```
      PROGRAM  BURST_PH
!
      CHARACTER  ANS
      REAL  PKH_CARLO(3)
      REAL  PH_SUMMATE(3), PKH_SUMMATE(3,3)
      REAL  PH_GAUSS(3), PKH_GAUSS(3,3)
      REAL  X_BURST_DISPERSION /2./, Y_BURST_DISPERSION /2./
      REAL  XDISP (2) /1., 4./, YDISP (2) /1., 5./
      REAL  XBIAS (2) /0., 1.2/, YBIAS (2) /0., 1.5/
      INTEGER  RNDS (2) /5, 20/, ROUNDS
      REAL  PKH_RND(3) /.1, .5, .9/
      REAL  RANGE (3) /200., 800., 3000./
      COMMON  X_BURST_BIAS, X_BURST_DISPERSION,
      1Y_BURST_BIAS, Y_BURST_DISPERSION,
      2X_DISPERSION, Y_DISPERSION,
      3X_HULL, Y_HULL, X_TURR, Y_TURR, ROUNDS, PKH_RND
!
      OPEN (1, FILE='BURST_PH', STATUS='NEW',
      1 CARRIAGECONTROL='LIST')
100   WRITE (*,'(A)') ' HULL LENGTH AND HEIGHT?'
      WRITE (1,'(A)') ' HULL LENGTH AND HEIGHT?'
      READ (*,'(2F6.0)') XHULL, YHULL
      WRITE (1,'(2F7.3)') XHULL, YHULL
      WRITE (*,'(A)') ' TURRET LENGTH AND HEIGHT?'
      WRITE (1,'(A)') ' TURRET LENGTH AND HEIGHT?'
      READ (*,'(2F6.0)') XTURR, YTURR
      WRITE (1,'(2F7.3)') XTURR, YTURR
!
      DO IDISP = 1, 2
          X_DISPERSION = XDISP(IDISP)
          Y_DISPERSION = YDISP(IDISP)
      DO IBIAS = 1, 2
          X_BURST_BIAS = XBIAS(IBIAS)
          Y_BURST_BIAS = YBIAS(IBIAS)
      DO IRNDS = 1, 2
          ROUNDS = RNDS(IRNDS)
      DO IRNG = 1, 3
          X_HULL = XHULL * 1000. / RANGE(IRNG)
          Y_HULL = YHULL * 1000. / RANGE(IRNG)
          X_TURR = XTURR * 1000. / RANGE(IRNG)
          Y_TURR = YTURR * 1000. / RANGE(IRNG)
          CALL  MONTE_CARLO (PH_CARLO, PKH_CARLO)
          CALL  SUMMATE (PH_SUMMATE, PKH_SUMMATE)
          CALL  GAUSS (PH_GAUSS, PKH_GAUSS)
3         FORMAT (A, 2F7.2)
4         FORMAT (/A, I5)
5         FORMAT (A, F6.0)
1         FORMAT (A, F5.2)
```

```
2          FORMAT (/18X, A)
11         FORMAT (A, F40.5)
12         FORMAT (A, 4X, 3F10.5)
           WRITE (1,'(//A)') '                                   X      Y'
           WRITE (1,3)      ' ROUND DISPERSION  =',
        1  XDISP(IDISP), YDISP(IDISP)
           WRITE (1,3)      ' BURST BIAS        =',
        1  XBIAS(IBIAS), YBIAS(IBIAS)
           WRITE (1,4)      ' ROUNDS   =', ROUNDS
           WRITE (1,5)      ' RANGE    =', RANGE(IRNG)
C *** PH output
            WRITE (1,*)
            WRITE (1,*)
           WRITE (1,1) ' PROB. of HIT'
            WRITE (1,1) '             Iterations'
           WRITE (1,2) '100       400       1600      2000'
           WRITE (1,11) ' MONTE_CARLO', PH_CARLO
           WRITE (1,12) ' SUMMATE', (PH_SUMMATE(K), K = 1, 3)
           WRITE (1,12) '   GAUSS', (PH_GAUSS(K), K = 1, 3)
C *** PKH output
           DO J = 1, 3
            WRITE (1,*)
            WRITE (1,*)
           WRITE (1,1) ' PROB. of KILL/HIT'
            WRITE (1,1) ' RND PKH  =', PKH_RND(J)
           WRITE (1,2) '100      400      1600     2000'
           WRITE (1,11) ' MONTE_CARLO', PKH_CARLO(J)
           WRITE (1,12) ' SUMMATE', (PKH_SUMMATE(K,J), K = 1, 3)
           WRITE (1,12) '   GAUSS', (PKH_GAUSS(K,J), K = 1, 3)
           END DO  ! J
        END DO  ! IRNG
        END DO  ! IRNDS
        END DO  ! IBIAS
        END DO  ! IDISP
        WRITE (*,'(A)') ' CONTINUE?'
        READ (*,'(A1)') ANS
        IF (ANS .NE. 'Y') STOP
        WRITE (*,'(///)')
        WRITE (1,'(///)')
        GO TO 100
        END
!
!
        FUNCTION  DFN (X)
!
!       FROM HASTINGS APPROXIMATIONS FOR DIGITAL COMPUTERS
!
        F = 0.
        AX = ABS (X)
        IF (AX .GE. 5.) GO TO 1
        F = (((((.5383E-5 * AX + .488906E-4) * AX
        1   + .380036E-4) * AX 1 + .0032776263) * AX
```

```
        1    + .0211410061) * AX + .0498673469) * AX + 1.
        F = .5 / ((F**8)**2)
1       IF (X .GE. 0.) F = 1. - F
        DFN = F
        END


        SUBROUTINE  MONTE_CARLO (PH, PKH)
!
        PARAMETER  REPS = 2000
        REAL PKH(3), KILL(3), KILLS(3)
        REAL  XXPH(50), XXPK(50)
        INTEGER  REP, RND, RNDS
        COMMON  X_BURST_BIAS, X_BURST_DISPERSION,
        1Y_BURST_BIAS, Y_BURST_DISPERSION,
        2X_DISPERSION, Y_DISPERSION,
        3X_HULL, Y_HULL, X_TURR, Y_TURR, RNDS, PKH_RND(3)
!
        INCLUDE  'RANDOM_NUMBERS'! Data for
        ! NRANDOM(2000), DEVIATE(2000,2)
!
C *** Initialize
        HITS = 0.
        KILL3(1) = 0.
        KILLS(2) = 0.
        KILLS(3) = 0.
C *** Calculate target boundaries.
        X2TURR = X_TURR / 2.
        X1TURR = -X2TURR
        X2HULL = X_HULL /2.
        X1HULL = -X2HULL
        Y2TURR = (Y_HULL + Y_TURR) / 2.
        Y1TURR = Y2TURR - Y_TURR
        Y2HULL = Y1TURR
        Y1HULL = -Y2TURR
!
        DO REP = 1, REPS
        ISEED = NRANDM (REP)
C *** Draw random numbers for PH, PK for each round in burst.
         DO  RND = 1, RNDS
            XXPH(RND) = BARN(ISEED)
            XXPK(RND) = BARN(ISEED)
         END DO
        X_BIAS = X_BURST_BIAS + X_BURST_DISPERSION *
2       1   DEVIATE(REP,1)
        Y_BIAS = Y_BURST_BIAS + Y_BURST_DISPERSION *
        1   DEVIATE(REP,2)
C *** Prob. of hit on hull  in X-direction
        T2 = (X2HULL - X_BIAS) / X_DISPERSION
        T1 = (X1HULL - X_BIAS) / X_DISPERSION
        X_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on hull in Y-direction
```

```
      T2 = (Y2HULL - Y_BIAS) / Y_DISPERSION
      T1 = (Y1HULL - Y_BIAS) / Y_DISPERSION
      Y_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in X-direction
      T2 = (X2TURR - X_BIAS) / X_DISPERSION
      T1 = (X1TURR - X_BIAS) / X_DISPERSION
      X_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in Y-direction
      T2 = (Y2TURR - Y_BIAS) / Y_DISPERSION
      T1 = (Y1TURR - Y_BIAS) / Y_DISPERSION
      Y_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit on target
      PH_TGT = X_PH_HULL * Y_PH_HULL + X_PH_TURR * Y_PH_TURR

C *** Simulate
      HIT = 0.
      KILL(1) = 0.
      KILL(2) = 0.
      KILL(3) = 0.
      DO RND = 1, RNDS
      IF (XXPH(RND) .LE. PH_TGT) THEN
          HIT = 1.
          IF (XXPK(RND) .LE. PKH_RND(1)) KILL(1) = 1.
          IF (XXPK(RND) .LE. PKH_RND(2)) KILL(2) = 1.
          IF (XXPK(RND) .LE. PKH_RND(3)) KILL(3) = 1.
      ENDIF
      END DO
      HITS = HITS + HIT
      KILLS(1) = KILLS(1) + KILL(1)
      KILLS(2) = KILLS(2) + KILL(2)
      KILLS(3) = KILLS(3) + KILL(3)
      END DO  ! REP
!
      PH = HITS / REPS
      IF (HITS .GT. 0.) THEN
          PKH(1) = KILLS(1) / HITS
          PKH(2) = KILLS(2) / HITS
          PKH(3) = KILLS(3) / HITS
      ELSE
          PKH(1) = PKH_RND(1)
          PKH(2) = PKH_RND(2)
          PKH(3) = PKH_RND(3)
      ENDIF
      END
!
!
      FUNCTION BARN (ISEED)
!
      INTEGER ABARN ,
     1        B15   ,
     2        B16   ,
     3        FHI   ,
```

```
     4          LEFTLO,
     5          PBARN ,
     6          XALO  ,
     7          XHI
      DATA      ABARN  /       16807/,
     1          B15    /       32768/,
     2          B16    /       65536/,
     3          PBARN  / 2147483647/
C
C*****THIS RANDOM NUMBER GENERATOR WAS DEVELOPED BY THE
C*****ASSOCIATION OF COMPUTING MACHINERY,INC., COPYRIGHT 1979,
C*****AND PRESENTED IN THE TEXT BOOK "SIMULATION MODELING AND
C*****ANALYSIS" BY AVERILL M. LAW AND W. DAVID KELTON, COPYRIGHT
C*****1982, CHAPTER 6, PAGE 227.
C
      XHI    = ISEED/B16
      XALO   = (ISEED-XHI*B16)*ABARN
      LEFTLO = XALO/B16
      FHI    = XHI*ABARN + LEFTLO
      K      = FHI/B15
      ISEED  = (((XALO-LEFTLO*B16)-PBARN)+(FHI-K*B15)*B16)+K
      IF (ISEED .LT. 0) ISEED=ISEED+PBARN
      BARN   = FLOAT(ISEED)*4.656612875E-10
C*****PRINT IF RANDOM NO. IS ZERO
C*****ERROR
      IF(BARN.LT.0.0 .OR. BARN.GT.1.0) THEN
        PRINT *, ' **** INVALID RANDOM NUMBER: ',BARN
        STOP
      ENDIF
      RETURN
      END


      SUBROUTINE  SUMMATE (PH, PKH)

      REAL  PH(3), PKH(3,3)
      INTEGER  XREP, YREP, RNDS
      INTEGER  REPS(3) /10, 20, 40/
      REAL  XPK(3), YPK(3)
      REAL  DEVIATE(40,3)
      DATA  (DEVIATE(J,1), J = 1, 10) /
     *  -1.64486,  -1.03643,  -0.67449,  -0.38532,  -0.12566,
     *   0.12566,   0.38532,   0.67449,   1.03643,   1.64486 /
      DATA  (DEVIATE(J,2), J = 1, 20) /
     *  -1.95997,  -1.43954,  -1.15035,  -0.93459,  -0.75541,
     *  -0.59776,  -0.45376,  -0.31864,  -0.18913,  -0.06271,
     *   0.06271,   0.18913,   0.31864,   0.45376,   0.59776,
     *   0.75541,   0.93459,   1.15035,   1.43954,   1.95997 /
      DATA  (DEVIATE(J,3), J = 1, 40) /
     *  -2.24140,  -1.78046,  -1.53413,  -1.35632,  -1.21334,
     *  -1.09162,  -0.98423,  -0.88715,  -0.79778,  -0.71436,
     *  -0.63566,  -0.56071,  -0.48878,  -0.41929,  -0.35178,
```

```
     *  -0.28584,  -0.22112,  -0.15731,  -0.09414,  -0.03133,
     *   0.03133,   0.09414,   0.15731,   0.22112,   0.28584,
     *   0.35178,   0.41929,   0.48878,   0.56071,   0.63566,
     *   0.71436,   0.79778,   0.88715,   0.98423,   1.09162,
     *   1.21334,   1.35632,   1.53413,   1.78046,   2.24140 /
!
      COMMON  X_BURST_BIAS, X_BURST_DISPERSION,
      1Y_BURST_BIAS, Y_BURST_DISPERSION,
      2X_DISPERSION, Y_DISPERSION,
      3X_HULL, Y_HULL, X_TURR, Y_TURR, RNDS, PKH_RND(3)
!
C *** Calculate target boundaries.
      X2TURR = X_TURR / 2.
      X1TURR = -X2TURR
      X2HULL = X_HULL /2.
      X1HULL = -X2HULL
      Y2TURR = (Y_HULL + Y_TURR) / 2.
      Y1TURR = Y2TURR - Y_TURR
      Y2HULL = Y1TURR
      Y1HULL = -Y2TURR
!
      DO K = 1, 3
      XPH = 0.
      XPK(1) = 0.
      XPK(2) = 0.
      XPK(3) = 0.
      DO XREP = 1, REPS(K)
      X_BIAS = X_BURST_BIAS + X_BURST_DISPERSION *
      1   DEVIATE(XREP,K)
C *** Prob. of hit on hull  in X-direction
      T2 = (X2HULL - X_BIAS) / X_DISPERSION
      T1 = (X1HULL - X_BIAS) / X_DISPERSION
      X_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in X-direction
      T2 = (X2TURR - X_BIAS) / X_DISPERSION
      T1 = (X1TURR - X_BIAS) / X_DISPERSION
      X_PH_TURR = DFN(T2) - DFN(T1)
!
      YPH = 0.
      YPK(1) = 0.
      YPK(2) = 0.
      YPK(3) = 0.
      DO YREP = 1, REPS(K)
      Y_BIAS = Y_BURST_BIAS + Y_BURST_DISPERSION *
      1   DEVIATE(YREP,K)
C *** Prob. of hit on hull in Y-direction
      T2 = (Y2HULL - Y_BIAS) / Y_DISPERSION
      T1 = (Y1HULL - Y_BIAS) / Y_DISPERSION
      Y_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in Y-direction
      T2 = (Y2TURR - Y_BIAS) / Y_DISPERSION
      T1 = (Y1TURR - Y_BIAS) / Y_DISPERSION
```

```
      Y_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit for a round
      PH_RND = X_PH_HULL * Y_PH_HULL + X_PH_TURR * Y_PH_TURR
C **  Prob. of hit for the burst
      YPH = 1. - (1. - PH_RND) **RNDS + YPH
C **  Prob. of kill for the burst
      YPK(1) = 1. - (1. - PH_RND * PKH_RND(1)) **RNDS + YPK(1)
      YPK(2) = 1. - (1. - PH_RND * PKH_RND(2)) **RNDS + YPK(2)
      YPK(3) = 1. - (1. - PH_RND * PKH_RND(3)) **RNDS + YPK(3)
      END DO  ! YREP
!
      XPH = YPH + XPH
      XPK(1) = YPK(1) + XPK(1)
      XPK(2) = YPK(2) + XPK(2)
      XPK(3) = YPK(3) + XPK(3)
      END DO  ! XREP
!
      PH(K) = XPH / REPS(K)**2
      PKH(K,1) = XPK(1) / XPH
      PKH(K,2) = XPK(2) / XPH
      PKH(K,3) = XPK(3) / XPH
      END DO  ! K
      END


      SUBROUTINE  GAUSS (PH, PKH)
!
      REAL  PH(3), PKH(3,3)
      INTEGER  XREP, YREP, RNDS
      INTEGER  REPS(3) /10, 20, 40/
      REAL  XPK(3), YPK(3)
      REAL  DEVIATE(40,3), WT(40,3)
!
      DATA  (DEVIATE(J,1), J = 1, 10) /
     * -2.22482, -1.49490, -0.99326, -0.57309, -0.18765,
     *  0.18765,  0.57309,  0.99326,  1.49490,  2.22482 /
      DATA  (WT(J,1), J = 1, 10) /
     *  .0333357, .0747257, .1095432, .1346334, .1477621,
     *  .1477621, .1346334, .1095432, .0747257, .0333357 /
!
      DATA  (DEVIATE(J,2), J = 1, 20) /
     * -2.70303, -2.09659, -1.70731, -1.40213, -1.14151,
     * -0.90787, -0.69168, -0.48697, -0.28946, -0.09604,
     *  0.09604,  0.28946,  0.48697,  0.69168,  0.90787,
     *  1.14151,  1.40213,  1.70731,  2.09659,  2.70303 /
      DATA  (WT(J,2), J = 1, 20) /
     *  .0088070, .0203007, .0313360, .0416384, .0509651,
     *  .0590973, .0658443, .0710481, .0745865, .0763767,
     *  .0763767, .0745865, .0710481, .0658443, .0590973,
     *  .0509651, .0416384, .0313360, .0203007, .0088070 /
!
      DATA (DEVIATE(J,3), J = 1, 40) /
```

```
     * -3.12759, -2.60178, -2.27780, -2.03268, -1.83041,
     * -1.65512, -1.49838, -1.35507, -1.22202, -1.09689,
     * -0.97806, -0.86429, -0.75455, -0.64810, -0.54434,
     * -0.44266, -0.34268, -0.24393, -0.14603, -0.04861,
     *  0.04861,  0.14603,  0.24393,  0.34268,  0.44266,
     *  0.54434,  0.64810,  0.75455,  0.86429,  0.97806,
     *  1.09689,  1.22202,  1.35507,  1.49838,  1.65512,
     *  1.83041,  2.03268,  2.27780,  2.60178,  3.12759 /
       DATA (WT(J,3), J = 1, 40) /
     *  .0022606, .0052491, .0082105, .0111229, .0139685,
     *  .0167301, .0193911, .0219355, .0243479, .0266139,
     *  .0287199, .0306531, .0324020, .0339560, .0353058,
     *  .0364433, .0373616, .0380552, .0385199, .0387530,
     *  .0387530, .0385199, .0380552, .0373616, .0364433,
     *  .0353058, .0339560, .0324020, .0306531, .0287199,
     *  .0266139, .0243479, .0219355, .0193911, .0167301,
     *  .0139685, .0111229, .0082105, .0052491, .0022606 /
!
       COMMON  X_BURST_BIAS, X_BURST_DISPERSION,
       1Y_BURST_BIAS, Y_BURST_DISPERSION,
       2X_DISPERSION, Y_DISPERSION,
       3X_HULL, Y_HULL, X_TURR, Y_TURR, RNDS, PKH_RND(3)
!
C *** Calculate target boundaries.
       X2TURR = X_TURR / 2.
       X1TURR = -X2TURR
       X2HULL = X_HULL /2.
       X1HULL = -X2HULL
       Y2TURR = (Y_HULL + Y_TURR) / 2.
       Y1TURR = Y2TURR - Y_TURR
       Y2HULL = Y1TURR
       Y1HULL = -Y2TURR
!
       DO K = 1, 3
       XPH = 0.
       XPK(1) = 0.
       XPK(2) = 0.
       XPK(3) = 0.
       DO XREP = 1, REPS(K)
       X_BIAS = X_BURST_BIAS + X_BURST_DISPERSION *
       1   DEVIATE(XREP,K)
C *** Prob. of hit on hull  in X-direction
       T2 = (X2HULL - X_BIAS) / X_DISPERSION
       T1 = (X1HULL - X_BIAS) / X_DISPERSION
       X_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in X-direction
       T2 = (X2TURR - X_BIAS) / X_DISPERSION
       T1 = (X1TURR - X_BIAS) / X_DISPERSION
       X_PH_TURR = DFN(T2) - DFN(T1)
!
       YPH = 0.
       YPK(1) = 0.
```

```
      YPK(2) = 0.
      YPK(3) = 0.
      DO YREP = 1, REPS(K)
      Y_BIAS = Y_BURST_BIAS + Y_BURST_DISPERSION *
      1   DEVIATE(YREP,K)
C *** Prob. of hit on hull in Y-direction
      T2 = (Y2HULL - Y_BIAS) / Y_DISPERSION
      T1 = (Y1HULL - Y_BIAS) / Y_DISPERSION
      Y_PH_HULL = DFN(T2) - DFN(T1)
C *** Prob. of hit on turret in Y-direction
      T2 = (Y2TURR - Y_BIAS) / Y_DISPERSION
      T1 = (Y1TURR - Y_BIAS) / Y_DISPERSION
      Y_PH_TURR = DFN(T2) - DFN(T1)
C *** Prob. of hit for a round
      PH_RND = X_PH_HULL * Y_PH_HULL + X_PH_TURR * Y_PH_TURR
C **  Prob. of hit for the burst
      YPH = (1. - (1. - PH_RND) **RNDS) * WT(YREP,K) + YPH
C **  Prob. of kill for the burst
      DO J = 1, 3
          YPK(J) = (1. - (1. - PH_RND * PKH_RND(J)) **RNDS)
      1     * WT(YREP,K) + YPK(J)
      END DO
      END DO  ! YREP
!
      XPH = YPH * WT(XREP,K) + XPH
      XPK(1) = YPK(1) * WT(XREP,K) + XPK(1)
      XPK(2) = YPK(2) * WT(XREP,K) + XPK(2)
      XPK(3) = YPK(3) * WT(XREP,K) + XPK(3)
      END DO  ! XREP
!
      PH(K) = XPH
      PKH(K,1) = XPK(1) / XPH
      PKH(K,2) = XPK(2) / XPH
      PKH(K,3) = XPK(3) / XPH
      END DO  ! K
      END
```

## APPENDIX C

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